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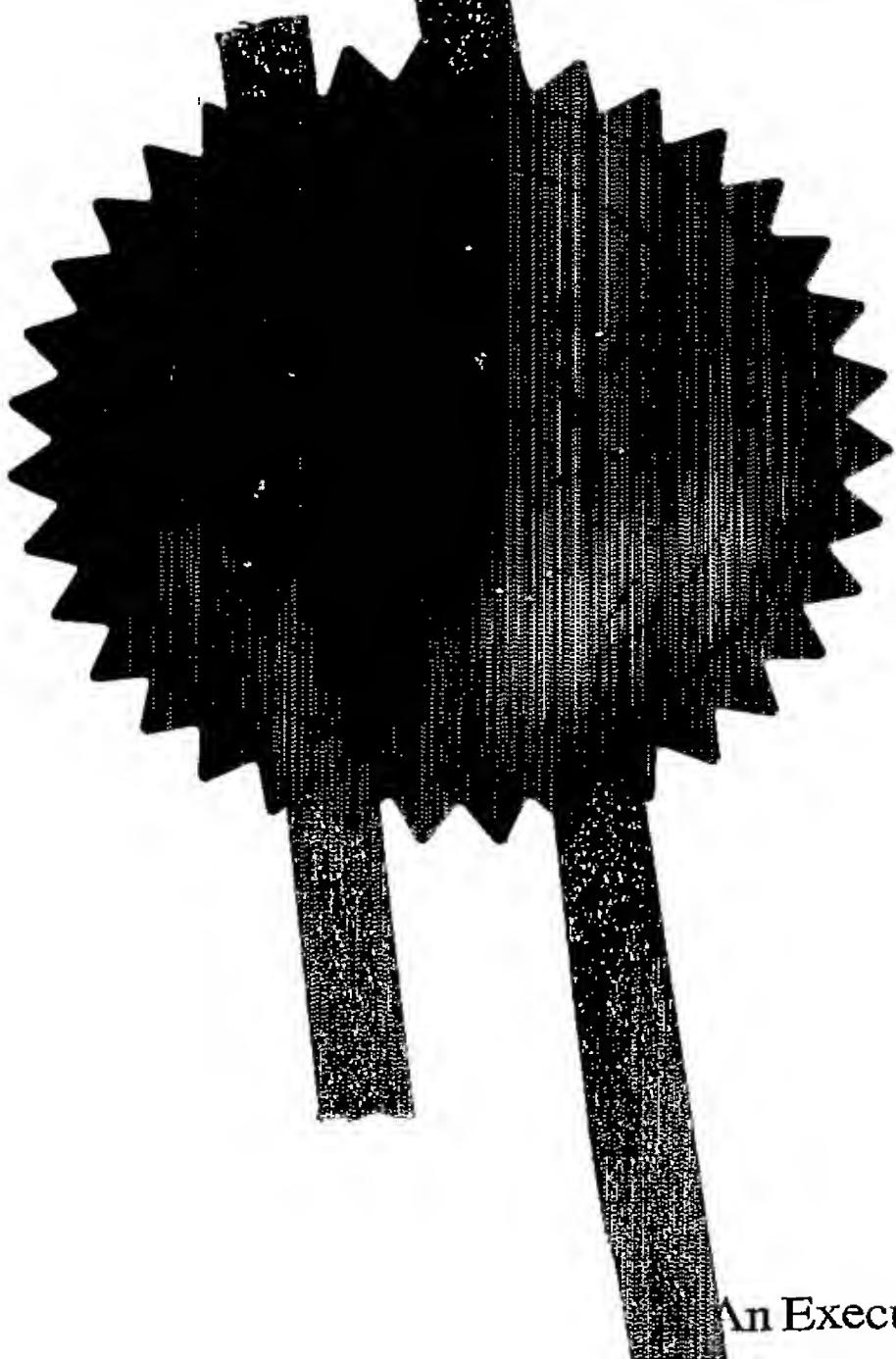
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0403955.8

23 FEB 2004

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Patents ADP number (if you know it)

United Kingdom

8302333001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

Solid State Laser Gain Medium

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Kilburn & Strode
20 Red Lion Street
London
WC1R 4PJ

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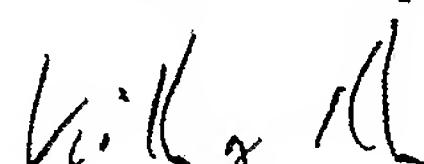
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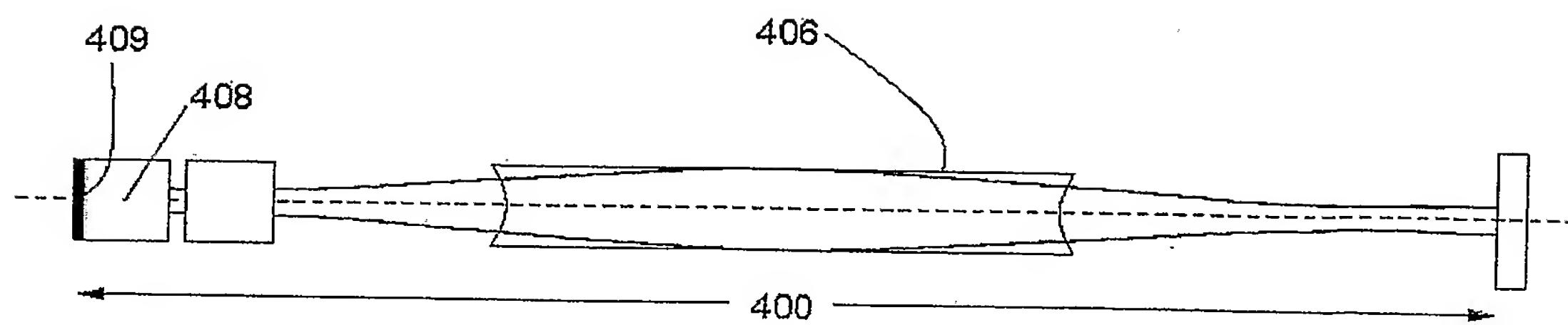


FIG. 4

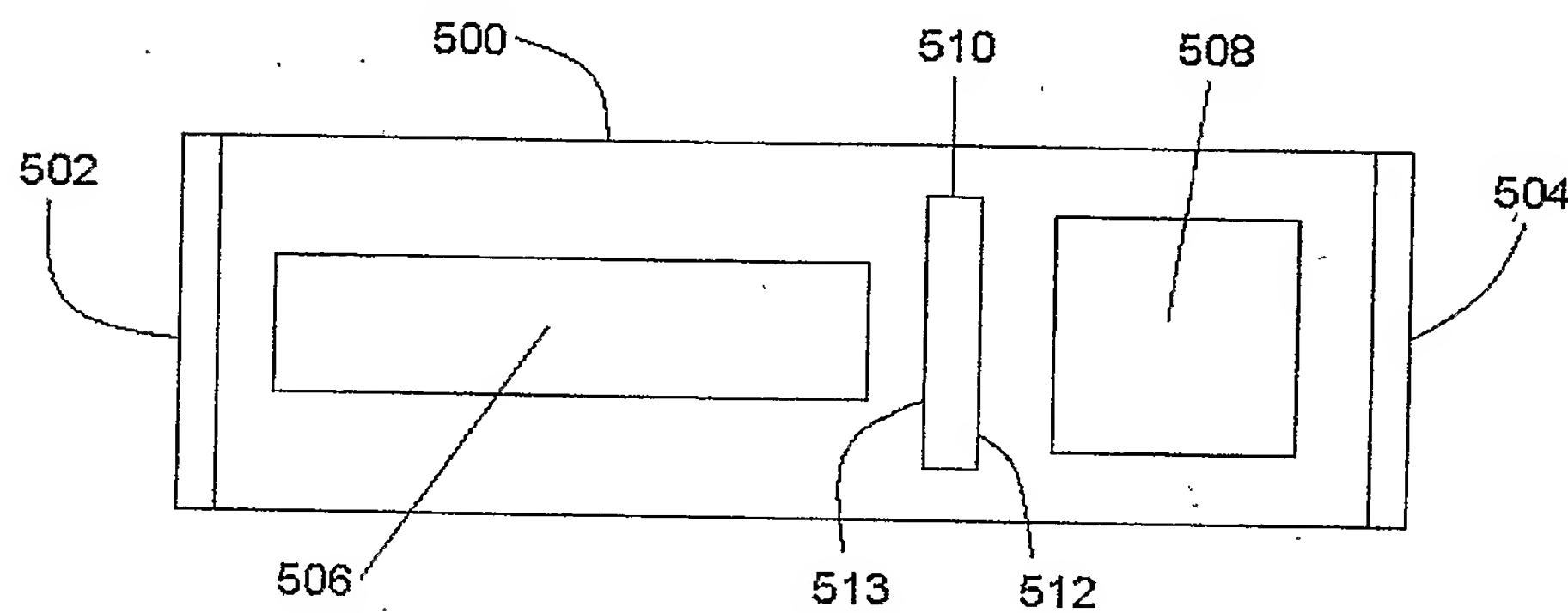


FIG. 5

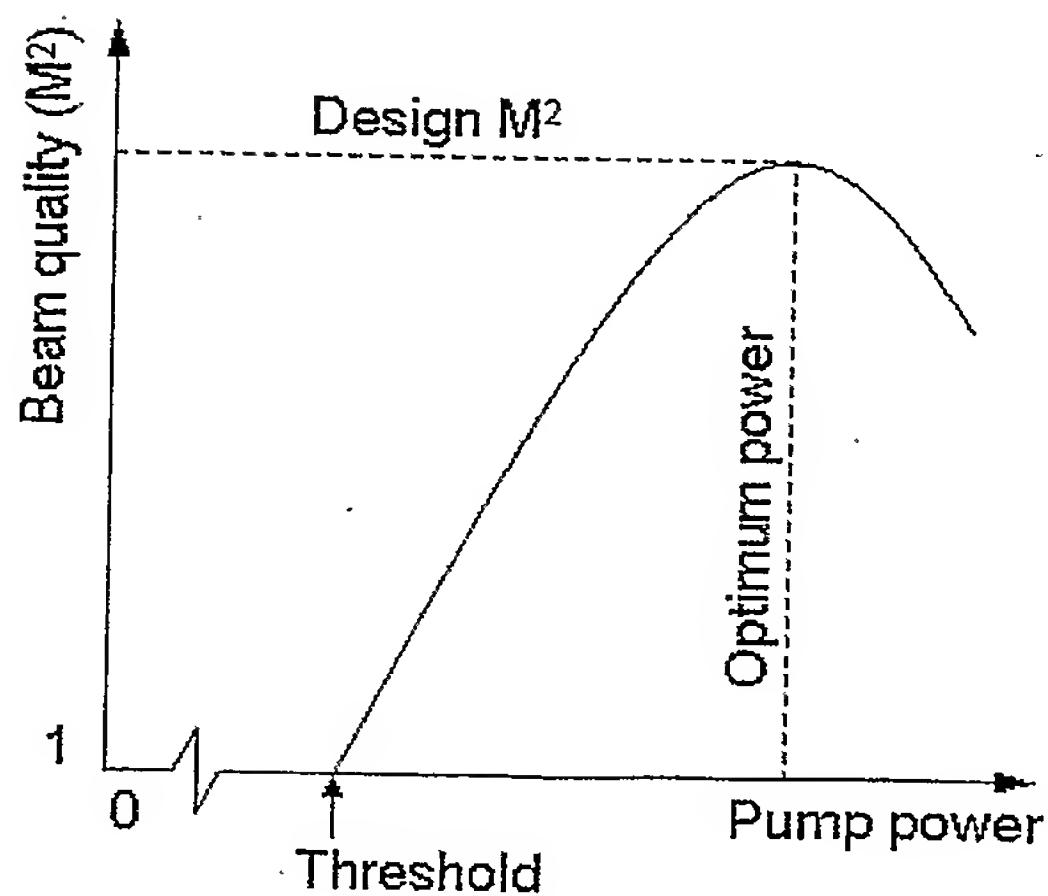
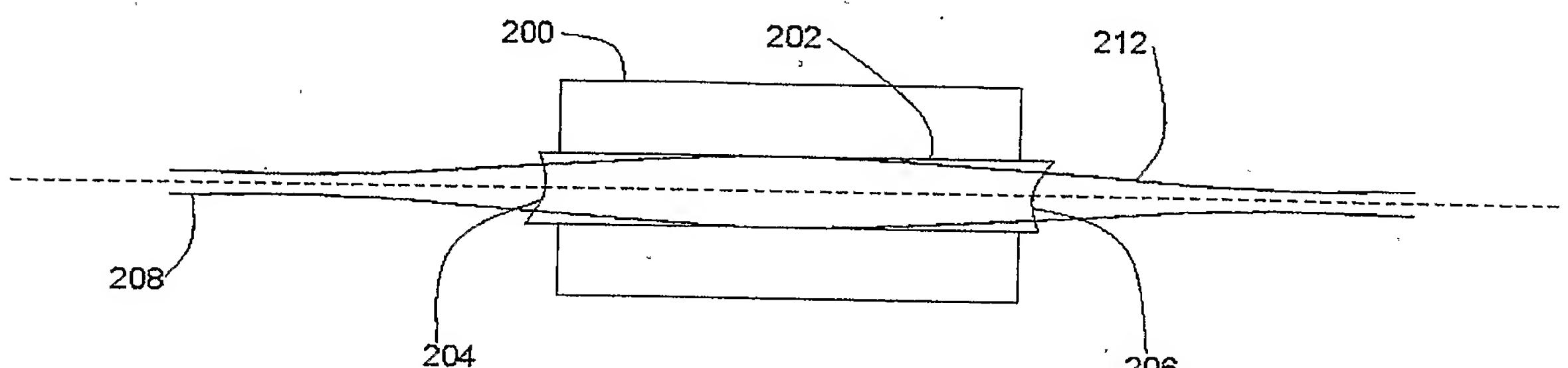
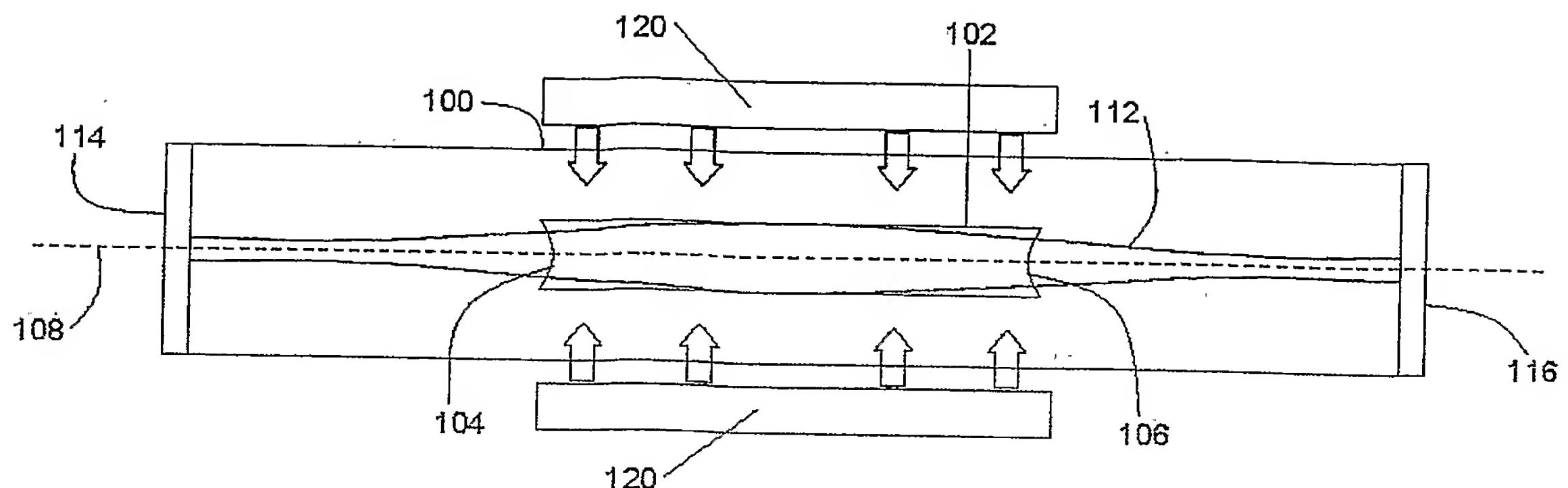
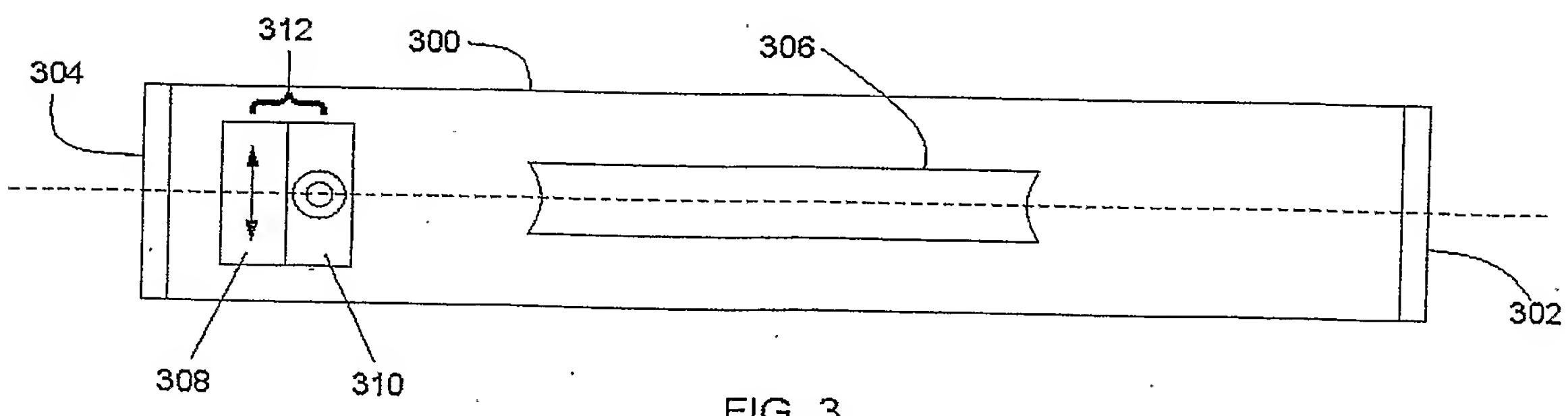


FIG. 6



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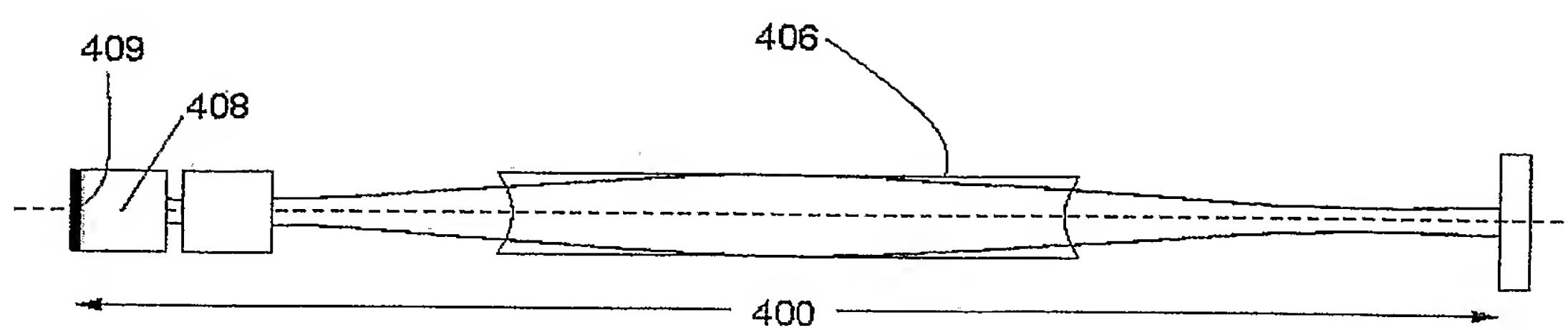


FIG. 4

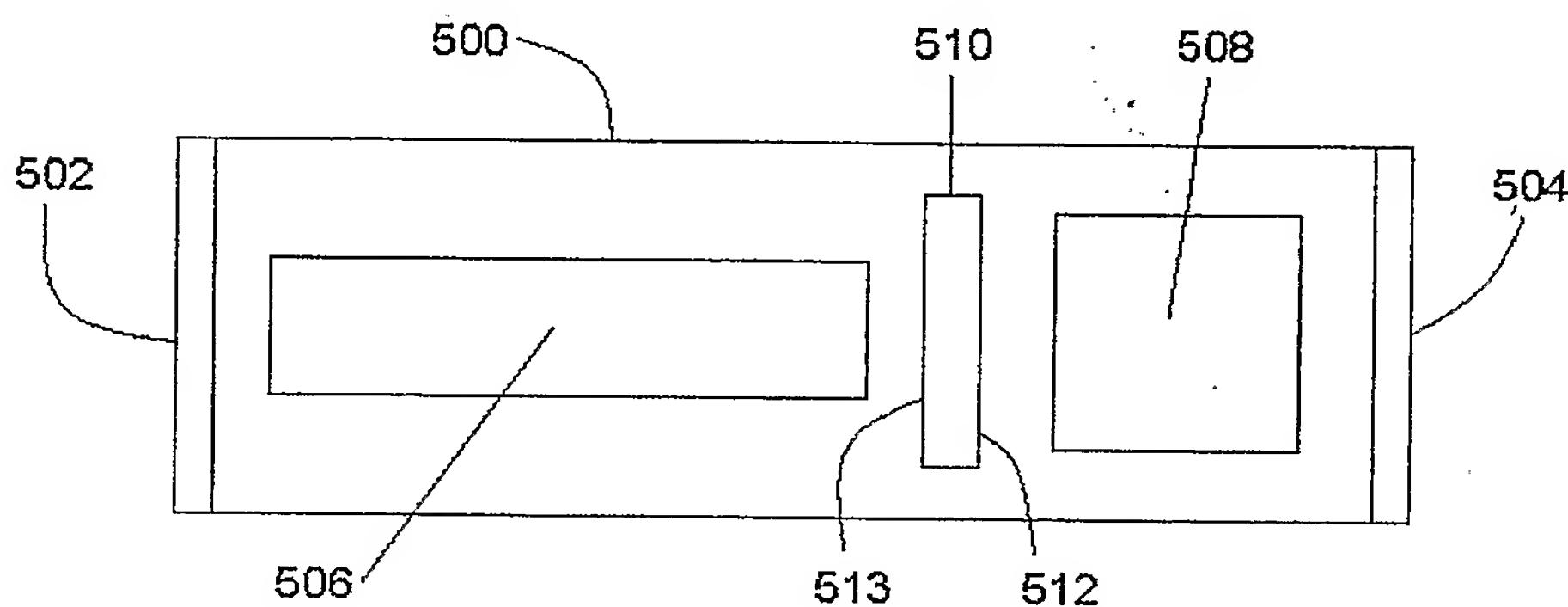


FIG. 5

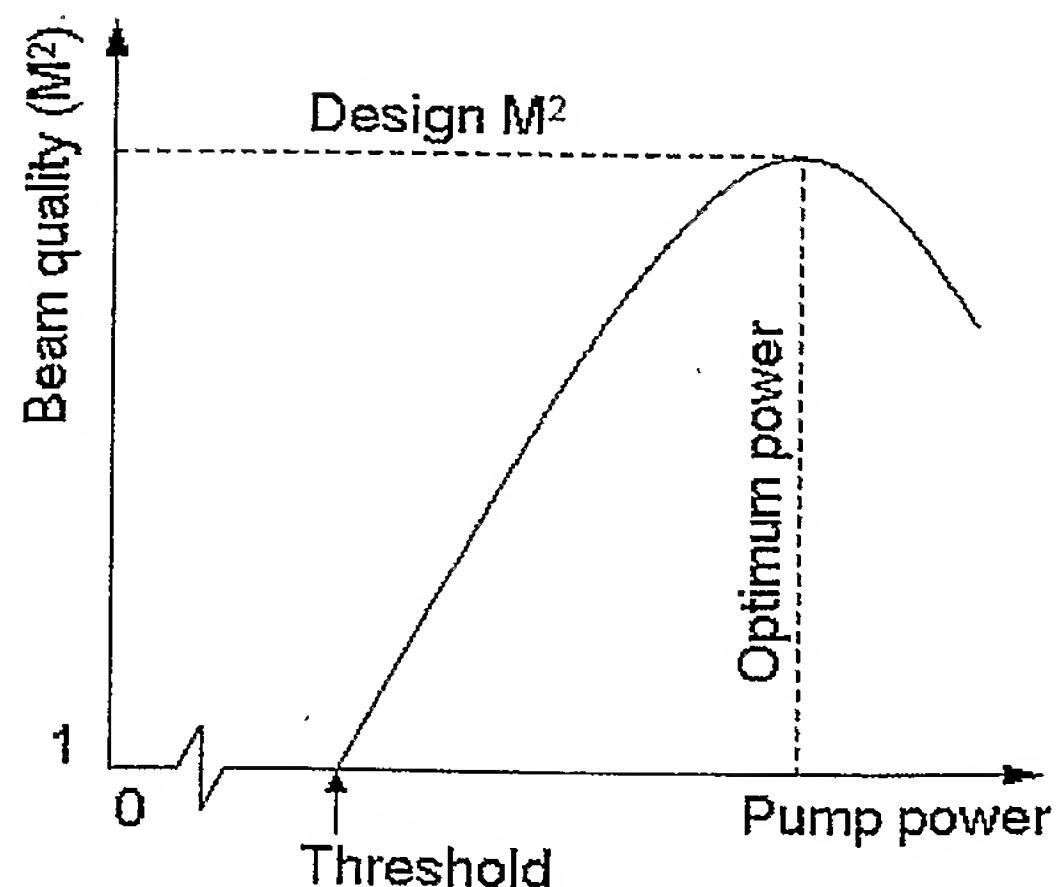


FIG. 6

SOLID STATE LASER GAIN MEDIUM

The invention relates to a solid state laser gain medium, in particular for use in a laser.

5

Various problems arise in known lasers, for example thermal effects which can contribute a positive lensing component owing to the heat deposited in the rod which diffuses radially to the cooling reservoir along the rod barrel. This provides a variable refractive index and hence a "thermal lens".

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Various solutions have been proposed for example curved mirrors in the laser cavity to compensate for the effect but these have various drawbacks, including restricted cavity stability.

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One solution is described in US6193711, which relates to a flashlamp pumped, gain switched, Er:YAG laser providing control of low repetition rate pulses from the laser by temporal control of the flashlamp current. Concave rod ends are used to provide complete thermal lensing compensation and the short cavity is formed by two plane mirrors.

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In this patent current pulses of different widths are used to output pulses of different energies and/or durations. In addition flashlamp control is used to maintain constant thermal lensing by keeping the thermal loading constant. The arrangement negates thermal lensing only for a specific power level.

25

Accordingly a problem with the arrangement described is that very high power, stable output for long cavities is difficult to achieve.

In another aspect it is well known to use techniques such as Q-switching to obtain pulsed operation of lasers. One known approach is described in

“Acousto-optic Q-Switches, page 501, Solid-State Laser Engineering, W. Koechner, Fifth Edition Springer-Verlag 1999”. According to the approach described there, use of a single acousto-optic (AO) modulator is provided as a Q-switch in a cavity comprising a gain medium and two cavity mirrors. The 5 Q-switch is used as a loss-modulator allowing the gain in the cavity to build up to high levels when the loss is high, which can be released as a large pulse when the loss is low. However, such an arrangement can suffer at high modulator powers where the Q-switch can become polarisation dependent meaning that it may not be effective for all polarisations of light.

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In a further aspect, frequency multiplication is known in lasers to provide desired output frequencies from a fundamental laser frequency. For example in US5943351 third, fourth, fifth and sixth order harmonics are generated from the fundamental laser wavelength. The design uses a linear configuration with 15 the gain medium, Q-switch, cavity mirrors and harmonic generation crystal all placed along the cavity optical axis. In particular the main cavity is bounded by mirrors and a second harmonic generator is provided within the cavity between a cavity mirror and a further internal mirror. The output of the cavity is received by a further harmonic generator external to the cavity which 20 combines the fundamental and second harmonic radiation.

The invention is set out in the claims. As a result of the invention in one embodiment a Q-switched, diode pumped, Nd:YAG high power laser is provided avoiding at least some of the problems with the prior art.

25

Embodiments of the invention will now be described, by way of example, with reference to the drawings of which:

Fig 1 is a schematic side view of a thermally modified laser cavity according to the present invention;

Fig 2 is a schematic side view of an amplifier module according to the present invention;

Fig 3 is a schematic side view of a Q-switched cavity according to the present invention;

5 Fig 4 is a schematic side view of a cavity incorporating a Q-switch according to another embodiment of the invention;

Fig 5 is a schematic side view of a laser cavity including a frequency doubler according to the present invention; and

Fig. 6 is a plot of laser beam quality (M^2) against laser pump power.

10

In overview and referring to Fig. 1 the invention makes use of a Neodymium doped YAG (Nd:YAG) gain medium (102) placed in an optical resonant cavity (100) formed by two mirrors (114, 116), one of which is partially reflective (output coupler) and one of which is totally reflective. The gain medium is 15 optically side-pumped, by laser diode bar emitters (120), ie. in a direction orthogonal to the gain medium longitudinal axis. The arrangement of the optical cavity and the diode bar emitters form an elongate chamber with the gain medium aligned co-axially at the centre of the arrangement. The diode pumped configuration enables the laser to operate at high average powers and 20 for it to be pumped very hard.

In order to achieve high power outputs from the laser, the gain medium is pumped by the high power laser diode bar emitters, causing thermal expansion effects in the gain medium. Such effects may lead to thermal lensing which 25 can have a detrimental effect on the output characteristics of the laser. However by providing a gain medium where the ends form curved surfaces, the invention alleviates sensitivity to thermal lensing effects. In particular the concave curvature on the rod ends contributes a negative lensing component to modify the strength of the thermal lens. The exact radius of curvature of the

rod end depends on the power of the pump diodes, the diameter of the rod, the length of the rod and the required performance and/or use of the gain module.

5 The thermal lens modification in turn improves the pulse repetition rate range and beam quality [M^2] of the laser output and allows the maximum amount of overlap between the cavity mode and the gain profile in the rod giving the highest extraction efficiency possible (ie. maximum power output). These improvements are normally particularly difficult to achieve when a long cavity has to be used in order to incorporate Q-switches and other cavity components.

10 In addition, the mirrors forming the optical cavity, as described above, can be planar, thus forming a Fabry-Perot (F-P) type cavity. The combination of curved gain medium ends mounted co-axially within an F-P cavity, further increase insensitivity to thermal lensing effects and changes in those effects resulting in yet further improved output characteristics. In the preferred 15 embodiment of a high power resonant Q-switched cavity in the kilohertz regime, this is particularly advantageous as changes in the pulse repetition rate can cause changes in thermal lensing conditions to which the cavity is robust.

20 In addition, the use of curved gain medium ends can also be employed externally to the laser oscillator in a laser amplifier. Optimal coupling between the oscillator and amplifier can be achieved through relay imaging. A typical approach to this is described in "Relay imaging of apertured beams, page 739, Lasers, A. Siegman, University Science Books 1986" in which the transfer of an apertured beam in an amplifier to another amplifier with optimal coupling is 25 achieved by use of a telescope between the two. This method allows the input beam to an amplifier to be optimally mode-matched to the gain profile. According to the invention, however, matching the thermal lens of the amplifier with the originating laser gain medium ensures mode matching between the respective media resulting in an overlap of the gain profiles. A

seed beam that is to be amplified will suffer positive lensing due to the induced thermal lens in the amplifier gain module. Thermal lens modification allows the effects of thermal lensing to be reduced and therefore to optimise gain overlap. Further to this, when the gain module amplifier is used in conjunction 5 with a laser oscillator using the same gain modules, relay imaging can be achieved without the use of an intermediate telescope. A further advantage with this system is that the spatial profile of the seed beam will be matched to the gain profile of the amplifier (mode-matching). Further gain modules may be added that mirror the configuration of the gain modules in the oscillator 10 cavity.

In addition, two orthogonally crossed acousto-optical (AO) modulators are introduced into the optical cavity between the laser medium and the one of the two mirrors forming the cavity, to provide a Q-switch. Generally, a Q-switch 15 is used as a loss-modulator allowing the gain in a cavity to build up to high levels when the loss is high, which can then be released as a large pulse when the loss is low. AO modulators consist of a transparent optical material that becomes a diffraction grating when a powerful radiofrequency (RF) signal is applied via a piezoelectric transducer. The diffraction grating ejects light out 20 of the cavity, therefore providing a loss. The depth of modulation that a particular polarisation experiences depends on, amongst other things, the RF power supplied. For most RF powers, one polarisation experiences more modulation than the other when the cell is used in compressional mode. For this reason, single AO Q-switches are often used in cavities with a single 25 polarisation. There is usually a particular (low) RF power that can be applied where the modulation is the same for two orthogonal polarisations. A single cell could be used for a low power, unpolarised laser in this regime of operation. However at very high laser powers (for example 100's of Watts) and therefore very high gain, a large depth of modulation is required to

Q-switch the cavity. For this reason the power applied to the AO modulators is turned up very high (up to 100 W) to maximise the loss modulation. This causes the modulation to be highly polarisation dependent and so two orthogonal cells are used according to the invention to achieve the required 5 modulation. The cells should be aligned according to either the Bragg or near Bragg regime for optimum performance.

Using crossed AO cells orthogonal to the optical axis of the laser cavity provides a non-polarisation sensitive hold-off which can support unpolarised, 10 multimode operation, even if the individual cells become polarisation sensitive as a result of high RF power operation.

Additionally, it is possible to replace the reflective planar mirror, as outlined above, by coating the external surface of the nearest AO modulator forming a 15 Q-switch with a high reflection (HR) material. The F-P cavity is thus formed of one planar partially reflective mirror (output coupler) and the rear HR coated surface of the AO modulator furthest from the gain module, thus negating the need for a cavity mirror. This also provides faster switching speeds, as the switch time is dependent on the beam size in the modulator. The beam size is 20 smallest at the cavity mirrors, so the fastest switching speed will be achieved at the extremes of the cavity.

The laser described herein is often used to produce bursts of short pulses. Owing to an excessive build up of gain, the first pulse in the burst can be 25 different (generally more intense) than the rest. In order to compensate for this a method of pulse control is provided that controls the gain by changing the pump laser diode power between bursts of pulses. If the time between bursts of pulses is long (hundreds of milliseconds) the thermal lens strength increases due to the lack of intracavity power. To control this, the diode power is

reduced slightly to change the strength of the lens to the same level it would be if the laser were still lasing. In order to compensate for the excessive gain build up just prior to the first pulse, the diode power is briefly taken below the cavity lasing threshold to deplete the gain from the gain module. The first 5 pulse will then experience the same gain as the rest of the pulse train. This method (applicable for any Q-switched, diode pumped laser), in conjunction with other AO pulse control methods (for example, First Pulse Suppression which is described in US4675872) provides full control of the pulses emitted by the laser for any duty cycle and repetition rate.

10

In addition, the optical cavity can include a frequency doubling component, for 15 second harmonic generation. The frequency doubling component is formed of a non-resonant sub-cavity and a frequency doubling crystal. The non-resonant sub-cavity replaces the partially reflective planar mirror (output coupler) of the F-P optical cavity and includes an additional dichroic planar mirror (in-line mirror) placed between the gain medium and the frequency doubling crystal. The cavity mirrors are highly reflective to the fundamental frequency of the cavity by virtue of appropriate coatings. In addition the additional in-line mirror reflects the doubled frequency but passes light at the fundamental 20 frequency, whilst the cavity mirror forming the other end of the non-resonant internal cavity passes the doubled frequency. The frequency doubling crystal can be any appropriate material such as LBO placed within the sub cavity. The advantage of such an arrangement is that second harmonic generation is supported for high power multimode operation (as well as fundamental TEM_{00} mode operation), and the output is all in the same direction of the same 25 frequency and is used directly, for example on a work piece.

Referring now to Fig. 1 a laser cavity (100) including a laser rod with thermal lens modification (102) can be seen in more detail. For the purposes of

simplicity, other components such as additional optics are not shown. The laser rod (102) is preferably formed of Nd:YAG and is mounted in the cavity (100) in any appropriate manner. In the preferred embodiment the laser is a high power laser (150 to 500 W), with very high pumping power (up to 1500 W) such that thermal effects in the laser rod become very significant and in particular "thermal lensing" takes place. Thermal lensing arises as a result of various physical mechanisms (for example the quantum defect of the gain medium) but all result in the generation of a thermal gradient across the cross-section of the laser rod (102) providing a variable refractive index and hence a lensing effect. As can be seen from Fig 1, the ends of the laser rod (104, 106) relative to the laser axis (108) are concavely curved to modify the strength of the thermal lensing. Appropriate optics, such as a quartz rotator in a dual gain module cavity or Faraday rotator in a single gain module cavity, can be introduced to compensate for any increased bi-focusing effects arising as a result of the end curvature.

The laser cavity (100) further includes mirrored ends (114, 116) providing, as is well known, a resonant cavity to allow lasing. In the preferred embodiment, the mirrors are flat, providing a Fabry-Perot cavity. As a result, the cavity (100) can support a multi-mode cavity mode over a range of strengths of thermal lens by virtue of the flat cavity mirrors (114, 116) and the profiled laser rod ends (104, 106).

The curvature polished onto the end of the rod can be chosen via two methods. This first method involves measuring the focal length of the thermal lens and then providing suitable radius of curvature on the rod ends to give the required cavity stability. The thermal focal length can be measured using a HeNe laser shone through a pumped rod with flat ends. The HeNe will be focused at a point equal to thermal focal length of the rod at 633 nm. This thermal focal

length can then be used in a cavity modelling software package (such as Paraxia) to model the behaviour of the cavity as a function of pump power. The second method involves calculating the focal length of the rod using heat diffusion and refractive index modification equations and then providing suitable radius of curvature on the rod ends to give the required cavity stability. Such a method has been described in "Chapter 7. Thermo-Optic Effects and Heat Removal, page 406, Solid-State Laser Engineering, W. Koechner, Fifth Edition Springer-Verlag 1999". The calculated thermal focal length can be used in a cavity modelling package as above. The cavity should be designed such that the lasing threshold is low (for high power operation) and the M^2 of the cavity mode should peak at the desired operational pump power. This then ensures maximum cavity stability and insensitivity to changes in thermal lensing due to repetition rate changes.

In particular, rather than negating thermal lensing, which can provide acceptable operation only under very specific operating conditions and provide unstable operation outside those conditions, the present invention utilises thermal lensing. This is achieved by designing the cavity such that a desired strength of thermal lens is achieved in the area of the preferred operating conditions. In particular the gain medium is profiled so as to operate, in conjunction with the other optical elements in the cavity, to provide an appropriate beam quality M^2 centred on a desired operating pump power. This can be further understood with reference to Fig. 6 which shows, for a given cavity design, the variation in M^2 against pump power. As can be seen, M^2 varies approximately parabolically with pump power and peaks at a specific centre value. Variations of pump power (and therefore thermal lens strength) around that centre value lead to only minor changes in the value of M^2 and hence only minor degradation of the beam quality. Accordingly the gain medium is profiled such that, in conjunction with thermal lensing, M^2 is

centred on the desired operating power of the laser. The cavity should be optically symmetrical so that the relationship between pump power and output power is approximately linear. Also the cavity should be long enough to be able to incorporate the Q-switches and other required cavity components.

5

Referring to Fig 2, a gain module (200) is shown including a gain rod (202). As discussed above, such a gain module can be coupled to the output of a laser cavity (100) to act as an amplifier. In this case, ensuring that the thermal lens strength of the gain rod (202) matches that of the laser rod (102) ensures a mode matched configuration to optimise gain overlap and therefore efficiency and output power. In order to prevent back reflection from the gain module (200) to the laser oscillator (100), the rod ends (204, 206) can be wedged or decentred such that back reflection of the laser beam (208) is directed away from the oscillator cavity (100).

10

The materials and fabrication of the components of the laser and the laser itself are well known to the skilled reader and are not described here. For example, the pump array can be any high power laser diode array with suitable emission wavelength to pump the gain medium, the laser rod can be of any appropriate material, for example Neodymium doped YAG single crystal or ceramic or any other suitable laser medium, and the laser cavity can be defined by any suitable high power laser mirrors such as those available from CVI Laser Inc.

20

As a result of the arrangement described with reference to Fig 1, high power, unpolarised, multi-mode laser output can be obtained with high pumping power and modification of the thermal lensing. In particular and as discussed in more detail below, unpolarised, nanosecond pulsed output can be obtained with maximum power efficiency.

Referring now to Fig. 3, a further embodiment of the invention is shown comprising; a laser gain medium (306), an optical cavity (300) defined by mirrors (302, 304), one of which is partially reflective as described above. Also provided between the gain medium and one of the mirrors is a Q-switch (312) comprising a pair of adjacent acousto-optical (AO) modulators (308, 310), formed of fused silica or other appropriate material, in Bragg alignment. As is well known, the AO modulators (308, 310) provide switching of laser radiation by preventing the build up of oscillations in the optical cavity (300). The AO modulators (308, 310) have orthogonal polarisation axes with respect to the other, passing light of all polarisations when deactivated. When the crossed AO modulators (308, 310) are activated by an RF signal, light oscillations of any polarisation are prevented, by blocking the optical path between the gain medium (306) and one of the mirrors (304), resulting in an increased population inversion in the gain medium (306). Preferably a pair of compressional (longitudinal), acousto-optic (AO) modulators are provided to Q-switch the cavity. Compression cells are used as they are capable of rapid switching which is important for high gain, fast build-up time lasers as described.

As a result of such an arrangement Q-switching can be achieved for pulsed unpolarised laser light resulting in increased power delivery. This increased power is due to a lack of sensitivity of the cavity to depolarisation losses. Often a polariser is used to reject depolarisation losses arising from thermal aberrations in the gain medium. By allowing all polarisation states to lase, no light is lost due to depolarisation.

Additionally, the embodiment of Fig. 3 can be modified, as shown in Fig. 4, where a single AO modulator or pair of adjacent crossed AO modulators, forming a Q-switch as described above, can replace the fully reflective or

output coupling cavity mirror. The AO modulator (408) at the extreme of the cavity (400) has a high reflection coating (409) on the side distal to the gain medium (406), such that it acts as a cavity mirror to reflect light within the cavity or to couple light out of the cavity. The AO modulator must be cut, 5 polished and coated such that it is pre-aligned according to the correct operation mode (ie. Bragg, near Bragg, Raman-Nath or near Raman-Nath) and that the mirror surface must retro-reflect light back into the cavity. This allows the AO modulators to be placed as close as possible to the ends of the cavity for fastest switching time. A fast switching time is important for high power, 10 high gain lasers as described earlier.

An addition to the high power, Q-switched laser described herein may be employed when it is used to provide bursts of pulses. When bursts of pulses are generated, pulses near the beginning of the burst may have anomalously 15 high or low energy (and/or intensity) and may be unstable. There are two sources of this problem: thermal variations (longer timescale, ~ 100 ms – ~ 1 s) and gain variations (shorter timescale, ~ 10 μ s – ~ 1 ms). The solution to the problem comes from modulation of the pump diode power. This can be achieved by suitable temporal modulation of the diode power supplies used to 20 power the gain modules. To correct for longer timescale problems, the diode power is reduced to a quiescent level (of the order of 5% below the normal operating power) between bursts of pulses to compensate for variations in the thermal lens. Diode power is briefly (~ 1 ms) further reduced (below the threshold power required for the cavity to lase) to compensate for gain 25 variations. This method (applicable for any Q-switched, diode pumped laser), in conjunction with other AO pulse control methods (for example, First Pulse Suppression) provides full control of the pulses of a burst emitted by the laser for any duty cycle and repetition rate.

Referring now to Fig 5, a further embodiment of the invention is shown comprising a laser cavity (500) bounded by mirrors (502, 504) and having therein a laser rod (506). In the embodiment shown, the laser rod has generally flat ends but it can be profiled in any appropriate alternative manner, as discussed in detail above.

Also provided in the cavity is a frequency doubler (508). The component can be any appropriate nonlinear crystal such as LBO. As is well known, the frequency doubler (508) provides an output laser beam having a doubled frequency relative to that input from the laser rod (506). Placed intermediate to the laser rod (506) and frequency doubling element (508) is an in-line mirror (510). The in-line mirror is coated, for example, on its side (512) adjacent to the frequency doubling element (508), with a high reflective coating at the doubled frequency to reflect light of the doubled frequency and an anti-reflection coating to pass light at the fundamental frequency. Also the other side of this optic (513) may be coated with an anti-reflection coating to pass light at the fundamental frequency. As a result, the mirror (510) forms with the cavity end mirror (504) of a non-resonant sub-cavity. Doubled frequency laser light is output from the cavity via the end mirror (504) which carries a highly reflective coating at the fundamental frequency and an anti-reflection coating at the doubled frequency.

It will be appreciated that any appropriate components can be used for the arrangement shown in Fig 5. For example, a suitable laser rod such as Nd:YAG can be adopted and the frequency conversion element can obtain any appropriate harmonic generation crystal in the form of any appropriate material such as, for example LBO for multimode or BBO for single mode (TEM_{00}) conversion. Similarly, the intermediate mirror (510) and cavity end mirrors can be of any appropriate type and can carry, for example, a coating such as a

multilayer, thin film dielectric coating to ensure appropriate frequency selection.

5 The conversion efficiency using this method is improved in three ways over standard extra-cavity doubling techniques. Firstly, intracavity doubling takes advantage of high intracavity intensities to increase the conversion efficiency due to the nonlinear nature of the process. Secondly, the intermediate mirror allows doubled light generated by passing either way through the doubling crystal to exit the laser collinearly and in the same direction. Thirdly, the 10 fundamental radiation cannot escape from the cavity except via frequency doubling. As a result a pure and immediately usable output is provided at the doubled frequency. Furthermore the collinear arrangement provides the advantage of simplicity over, for example a folded cavity.

15 In the frequency doubling process, the temperature of the doubling crystal is critical to the conversion efficiency and stability of the laser. The warm-up time of the laser can be dramatically improved by using a crystal pre-cooling technique. When the laser makes the transition from a non-lasing to lasing state, the thermal loading on the frequency doubling crystal increases suddenly. 20 As a consequence, the temperature of the crystal increases reducing the doubling efficiency. The crystal temperature control system then takes time to reduce the temperature of the crystal to the optimum conversion point. The warm-up time is reduced by setting the crystal temperature to a value lower than the optimum doubling temperature while the laser is in the non-lasing state. When the laser is then turned on, the sudden increase in thermal loading increases the temperature of the crystal towards the optimum conversion point. 25 The set point of the cooling system is increased towards the optimum conversion temperature as the crystal temperature increases thus reducing the temperature overshoot and warm-up time.

The doubling crystal cooling system comprises: a heat conductive crystal mount (for example, made of copper); a heat transfer pump (such as a thermo-electric cooler); a heat sink (such as a water cooled block); and a temperature sensor placed close to the crystal. The crystal is cooled by pumping heat from the crystal mount to the heat sink and is heated by pumping heat from the sink to the crystal mount. The temperature of the crystal is set by and controlled by any suitable Proportional Integral Differential temperature controller (PID controller). An example temperature set-point might be 25°C.

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It will be appreciated that a laser of the type described can be adopted for a range of possible applications, for example laser ablation, cutting, drilling.

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It will be appreciated that components and elements from the various embodiments described above can be interchanged and juxtaposed as appropriate. Although the discussion is directed to an Nd:YAG laser, any appropriate laser material can be adopted. Similarly, any appropriate cavity configuration and pumping scheme can be implemented as well as any appropriate mode of pulsed or continuous operation.

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Claims

1. A solid state laser gain medium having first and second ends along a laser optical axis in which at least one end is profiled to provide a level of thermal lensing at a predetermined operating power such that a predetermined beam quality is achieved at the predetermined operating power.
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2. A medium as claimed in claim 1 in which the predetermined beam quality is centred on a maximum at the predetermined operating pump power.
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3. A medium as claimed in claim 1 or claim 2 in which both ends of the medium are profiled.
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4. A medium as claimed in any preceding claim in which the gain medium is formed of Nd:YAG.
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5. A laser oscillator cavity including a medium as claimed in any preceding claim.
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6. A cavity as claimed in claim 5 further comprising flat cavity end reflectors.
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7. A cavity as claimed in any of claims 4 to 6 further comprising a Q-switch having first and second acousto-optic cells and respective first and second non-parallel polarisation orientations.
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8. A cavity as claimed in any of claims 5 to 7 further including a Q-switch comprising at least one acousto-optic cell having a reflective end forming a cavity end reflector.

9. A cavity as claimed in any of claims 4 to 8 further comprising a frequency converter and a frequency selective reflector between the laser gain medium and the frequency converter.

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10. A laser including a medium as claimed in any of claims 1 to 3 or a cavity as claimed in any of claims 4 to 9.

11. A laser as claimed in claim 10 further comprising a side-pumping diode element.

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12. A Q-switch for a laser comprising first and second acousto-optic cells in respective first and second non-parallel polarisation orientations.

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13. A Q-switch as claimed in claim 12 further comprising a reflective surface arranged to form a laser cavity mirror.

14. A laser including a Q-switch as claimed in claim 12 or claim 13.

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15. A Q-switch or a laser comprising at least one acousto-optic cell having a reflective surface arranged to form a laser cavity mirror.

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16. A laser cavity comprising a first end reflector, an output end reflector and a gain medium provided therebetween, the cavity further comprising a frequency converter between the gain medium and the output end reflector and a frequency selective reflector between the gain medium and the frequency converter wherein the frequency selective reflector and the output end reflector are arranged to output laser light converted by the frequency converter to be used at a target at the converted frequency.

17. A cavity as claimed in claim 16 in which the frequency converter is a second harmonic generator.

5 18. A cavity as claimed in claim 16 or 17 in which the output end reflector reflects the fundamental frequency generated by the gain medium.

10 19. A cavity as claimed in any of claims 16 to 18 in which the laser cavity elements are aligned on a common physical axis.

21. A laser ablation device comprising a laser as claimed in claim 10, claim 14 or claim 20.

15 22. A method of profiling a laser gain medium end comprising to provide a level of thermal lensing at a predetermined pump power such that a predetermined beam quality is achieved at the predetermined pump power.

20 23. A method of controlling pumping of a Q-switched pulsed laser comprising reducing pump power to a quiescent level between bursts of laser pulses.

24. A method of controlling pumping in a Q-switched, pulsed laser comprising reducing pump power below the laser cavity lasing threshold prior to full-power pumping.

25. A method of converting laser frequency in a laser cavity comprising cooling a frequency converter in the laser cavity to below an optimum frequency conversion temperature while the laser is in a non-lasing state.